

TECHNICAL NOTE

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A real-time PCR assay with improved specificity for detection and discrimination of all clinically relevant *Bordetella* species by the presence and distribution of three Insertion Sequence elements

Lieuwe Roorda¹, Johannes Buitenwerf¹, Jacobus M Ossewaarde^{1,2}, Anneke van der Zee^{1*}**Abstract**

Background: In Dutch laboratories molecular detection of *B. pertussis* and *B. paraptussis* is commonly based on insertion sequences *IS481* and *IS1001*, respectively. Both IS elements are more widely spread among *Bordetella* species. Both *Bordetella holmesii*, and *B. bronchiseptica* can harbour *IS481*. Also, *IS1001* is found among *B. bronchiseptica*. *IS481*, and *IS1001* based PCR thus lacks specificity when used for detection of specific *Bordetella* spp.

Findings: We designed a PCR based on *IS1002*, another IS element that is present among *Bordetella* species, and exploited it as a template in combination with PCR for *IS481*, and *IS1001*. In combining the PCRs for *IS481*, *IS1001*, and *IS1002*, and including an inhibition control, we were able to detect and discriminate all clinically relevant *Bordetella* species.

Conclusions: We developed an improved PCR method for specific detection of *B. pertussis*, *B. paraptussis*, *B. holmesii*, and *B. bronchiseptica*.

Background

The genus *Bordetella* is comprised of 8 species, 4 of which are known to infect humans; *B. pertussis*, *B. paraptussis*, *B. holmesii*, and *B. bronchiseptica*. The most important cause for whooping cough is *B. pertussis*, followed by *B. paraptussis*. *Bordetella holmesii* was first described in 1995 [1], and has since been isolated from patients with a serious underlying disease [2-5]. *B. bronchiseptica* is usually restricted to animals but occasionally is isolated from immunocompromised patients [6,7].

A large number of PCR (polymerase chain reaction) assays have been described for detection of *Bordetella pertussis* and *B. paraptussis*, and more recently *B. holmesii* [8-14]. Most PCRs are based on detection of the insertion sequence elements *IS481*, and *IS1001*, because they exist in multiple copies in the chromosome. A high copy number of PCR target, contributes to the sensitivity of detection. *IS481* (1053 bp) shows a high degree of

homology between different members of *Bordetella* species of 96%. All *IS1001* (1306 bp) sequences known in Genbank are 100% homologues, as is *IS1002* (1040 bp). The degree of homology between *IS481*, *IS1001*, and *IS1002* is less than 5%.

The insertion sequences (IS) that are present in *Bordetella* spp., are distributed according to species and/or host specificity. For example, *IS1001* is found in all *B. paraptussis*, but *IS1002* is found only in *B. paraptussis* that infect humans and is absent from *B. paraptussis* sheep isolates [15]. *B. pertussis* harbors both *IS481* and *IS1002* while some *B. bronchiseptica* strains may have either *IS481* or *IS1001* [15]. *B. holmesii* only has *IS481*.

Due to the distribution of *IS481*, and *IS1001*, PCRs for *B. pertussis* and *B. paraptussis* lack specificity [16]. In recent years many newly developed PCRs were introduced with improved specificity but often with a compromise to sensitivity [11,13,14].

The aim of this study was to improve the specificity of PCR by including another IS element, *IS1002*, as target in PCR. *IS1002*, in addition to *IS481*, and *IS1001*, which

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enables discrimination of *B. pertussis*, *B. holmesii*, *B. parapertussis*, and *B. bronchiseptica*.

Methods

IS1002 has not been exploited before as a template in PCR detection. We developed a specific *IS1002* PCR (Table 1) to improve our ability to recognize the correct *Bordetella* species, and to combine it with *IS481*, and *IS1001* specific PCRs. Addition of Phocine Herpes Virus (PhHV) as internal control acts to monitor the extraction as well as the efficiency of amplification [17].

We investigated standard laboratory strains of *Bordetella* (kindly provided by Dr. Frits Mooi and Kees Heuvelman, Laboratory for Vaccine Preventable Diseases, National Institute of Public Health and the Environment, Bilthoven, The Netherlands), which are shown in Table 2. Since detection of *B. pertussis* is of highest concern, we investigated the performance of the newly developed PCR on 100 clinical samples that were previously positive. To verify the specificity of the PCR we investigated 20 clinical respiratory tract samples that were suspect for other pathogens than *Bordetella*. Prior to PCR, laboratory strains were diluted and boiled to release DNA (equivalent to approximately 5 cells/ μ l). Clinical samples were extracted using EasyMAG (Bio-merieux, Grenoble, France).

PCRs for detection of *IS481*, *IS1001*, and *IS1002* were performed in a reaction mixture of 25 μ l containing 0.5 μ M of *IS481* and *IS1001* primers, 0.8 μ M and 0.6 μ M of *IS1002* Forward and Reverse primer, respectively, and 0.2 μ M of PhHV primers. Probes (Table 1) were added with concentrations of 0.14, 0.14, 0.16, and 0.08 μ M for respectively *IS481*, *IS1001*, *IS1002*, and the internal control in PCR reaction mix (Sigma -Aldrich (E3004), Munich, Germany). Nine μ l of template DNA was

Table 1 DNA sequences of primers and probes directed against three IS elements and the internal control Phocine Herpes Virus (PhHV)

Template	Primer/probe (label)	Sequence (5'-3')
<i>IS481</i>	Forward primer	GCCGGATGAACACCCATAAG
	Reverse primer	GCGATCAATTGCTGGACCAT
	Probe (FAM)	CGATTGACCTTCCTACGTC-MGB
<i>IS1001</i>	Forward primer	AATTGCTGCAAGCCAACCA
	Reverse primer	CCAGAGCCGTTTGAGTTCTGT
	Probe (VIC)	ACATAGACCGTCAGCAG-MGB
<i>IS1002</i>	Forward primer	CTAGGTCGAGCCCTTCCTGTTAAC
	Reverse primer	GCGGGCAAGCCACTTGTGA
	Probe (CY5)	CATCGTCCAGTTCGTGTCATCACCC-BBQ
PhHV	Forward primer	GGGCGAATCACAGATTGAATC
	Reverse primer	GCGGTTCCAAACGTACCAA
	Probe (NED)	TTTTATGTGTCCGCCACCA-MGB

Table 2 Results of PCRs for detection of *IS481*, *IS1001*, and *IS1002*, and the interpretation for identification of clinically relevant *Bordetella* species

<i>Bordetella</i> subspecies*	<i>IS481</i>	<i>IS1001</i>	<i>IS1002</i>	identification
<i>pertussis</i>	+	-	+	<i>B. pertussis</i>
<i>parapertussis</i>	-	+	+	<i>B. parapertussis</i>
<i>holmesii</i>	+	-	-	<i>B. holmesii</i> / <i>B. bronchiseptica</i>
<i>bronchiseptica</i>	-	+	-	<i>B. bronchiseptica</i>
<i>petrii</i>	-	-	-	identification not possible
<i>hinzii</i>	-	-	-	identification not possible

*Strains were kindly provided by Dr. Frits Mooi and Kees Heuvelman, Laboratory for Vaccine Preventable Diseases, National Institute of Public Health and the Environment, Bilthoven, The Netherlands.

added. Amplification was carried out on an ABI 7500 Real-Time PCR system (Applied Biosystems (ABI), Nieuwerkerk a/d IJssel, The Netherlands). The temperature profile included initial denaturation of 4 min. at 94°C, followed by 50 cycles of 94°C for 15 sec., and 60°C for 1 min. Cycle threshold (Ct) values were determined automatically using the ABI SDS software.

Results

Evaluation of sensitivity

In order to evaluate the performance of the combination of all four PCRs in a multiplex format performed on standard laboratory strains (Table 2): *IS481*, *IS1001*, *IS1002*, and the internal control, we compared Ct values to each single PCR. No significant differences were found (not shown). Since *IS481* is present with a much higher copy number in *B. pertussis* than *IS1002* (approximately 200 and 10 copies, respectively), Ct values of *IS481* were on average 3.7 lower compared to Ct values of *IS1002* detection. Of a 10 CFU/ml dilution of *B. pertussis* cells both *IS481* and *IS1002* were positive with Ct values of respectively 30.6 and 34.4. The sensitivity of *B. parapertussis* detection was comparable with that using only *IS1001* as target.

Evaluation of specificity

To evaluate the specificity of each IS-based PCR, laboratory strains of most known *Bordetella* species (with exception of *B. avium* and *B. trematum*; Table 2), were subjected to the IS-based PCRs. Results were as was expected (Table 2).

To investigate whether all targets were amplified with high fidelity, and would not confound the specificity of detection, we made serial dilutions and subjected these to PCR. With limiting concentrations of *B. pertussis* bacteria, detection of *IS1002* is lost before detection of *IS481*, because of the difference in copy number.

To ensure specificity and to assess a cut-off Ct value for *B. pertussis*, 100 previously positive clinical samples were subjected to PCR. Only when Ct values of *IS481* >37, *IS1002* was negative (2% of 100 samples). Thus, a cut-off of Ct 35 should be taken for *IS481*. In 20 respiratory tract samples suspect for other pathogens, no *Bordetella* positives were found. With *B. parapertussis* PCR detection, similar Ct values of *IS1001* and *IS1002* were found, and hence no cut-off Ct values are necessary for *IS1001*, and *IS1002*.

Quality assessment

In addition, the multiplex IS-based PCR was evaluated using the External Quality Assessment Programme of *Bordetella pertussis* from the Quality Control for Molecular Diagnostics (QCMD, Glasgow, UK). The QCMD panel of samples consisted of 5 *B. pertussis* in a range of concentrations, 1 *B. parapertussis*, 1 *B. holmesii*, 2 *B. bronchiseptica*, 1 *B. hinzii*, 1 *Haemophilus influenza*, and 1 negative sample. Using our newly developed PCR we correctly identified *B. pertussis* even in the lowest concentration of 10 CFU/ml, and *B. parapertussis*. *B. holmesii* and one *IS481* containing *B. bronchiseptica* were recognized correctly and not as *B. pertussis*. *Haemophilus influenza* did not cross react with any of the targeted IS elements.

Discussion

In this study we included *IS1002* as target in PCR based detection of *Bordetella*, in addition to *IS481* and *IS1001*, which is the commonly used PCR in The Netherlands. We aimed to improve the specificity of PCR because the addition of *IS1002* enables the discrimination of *B. pertussis*, *B. parapertussis*, *B. holmesii*, and *B. bronchiseptica*.

In the final report of QCMD (Pierard, D., O. Soetens, and G. Ieven. *Bordetella pertussis* (BPDNA09) EQA Pilot Study. February 2010. QCMD, Glasgow UK.), a high degree of false positivity was observed for detection of *B. pertussis*. It appeared that more than 80% of laboratories contributing to the study used a PCR that is based on *IS481* and this accounts for the large proportion of false positive results. Indeed, *IS481* positive samples could either be positive for *B. pertussis*, *B. holmesii*, or *B. bronchiseptica*. Here, we have shown that in our PCR assay these organisms can be discriminated from one another. There are however some limitations. In a previous study [15] it was shown that *IS481* is very rarely found among *B. bronchiseptica* (1% of strains), in contrast to *IS1001* that was found in approximately 50% of the studied strain collection. Consequently, approximately 50% of *B. bronchiseptica* carry no known IS elements and thus cannot be detected by IS-based PCR. *B. bronchiseptica* strains that contain a copy of *IS481*

cannot be discriminated from *B. holmesii* using IS-based PCRs. If PCR presents a single *IS481* positive signal, one might re-investigate the sample using the *B. holmesii* specific PCR targeting the *recA* gene that was described earlier [18] to discriminate from *B. bronchiseptica*.

The performance of our assay may fail if clinical samples might contain more than one *Bordetella* species. However, after more than 15 years of experience with PCR detection of *B. pertussis* (*IS481*) and *B. parapertussis* (*IS1001*), we did not find more than one *Bordetella* species present in clinical specimens.

During the evaluation, we sometimes observed a weak positive signal for *IS481* (Ct > 37) from *B. hinzii*, although high concentrations of this organism were negative in PCR. This may indicate that *B. hinzii* might contain an *IS481*-like sequence that does not exactly match our PCR. As *B. hinzii* is solely confined to birds, this finding will not confound PCR based on *IS481*, *IS1001* and *IS1002* for detection and discrimination of the clinically relevant *Bordetella* species.

Conclusions

In conclusion, we have developed a real time PCR with improved specificity for detection and discrimination of all clinically relevant *Bordetella* species.

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Authors' contributions

LR carried out the molecular genetic studies, participated in the design of PCR and drafted the manuscript. JB and JMO participated in coordination of the study and helped to draft the manuscript. AZ conceived of the study, and participated in the design. All authors read and approved the final manuscript.

Competing interests

The author(s) declare that they have no competing interests.

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References

1. Weyant RS, Hollis DG, Weaver RE, Amin MF, Steigerwalt AG, O'Connor SP, Whitney AM, Daneshvar MI, Moss CW, Brenner DJ: *Bordetella holmesii* sp. nov., a new gram-negative species associated with septicemia. *J Clin Microbiol* 1995, **33**(1):1-7.
2. Dörbecker C, Licht C, Körber F, Plum G, Haefs C, Hoppe B, Seifert H: Community-acquired pneumonia due to *Bordetella holmesii* in a patient with frequently relapsing nephrotic syndrome. *J Infect* 2007, **54**(4):e203-5.
3. Greig JR, Gunda SS, Kwan JTC: *Bordetella holmesii* bacteraemia in an individual on haemodialysis. *Scand J Infect Dis* 2001, **33**(9):716-7.

4. McCavit TL, Grube S, Revell P, Quinn CT: *Bordetella holmesii* bacteremia in sickle cell disease. *Pediatr Blood Cancer* 2008, **51**(6):814-6.
5. Shepard CW, Daneshvar MI, Kaiser RM, Ashford DA, Lonsway D, Patel JB, Morey RE, Jordan JG, Weyant RS, Fischer M: *Bordetella holmesii* bacteremia: a newly recognized clinical entity among asplenic patients. *Clin Infect Dis* 2004, **38**(6):799-804.
6. Won KB, Ha GY, Kim JS, Kang HJ, Tak WT, Lee JH: Relapsing Peritonitis Caused by *Bordetella bronchiseptica* in Continuous Ambulatory Peritoneal Dialysis Patient: A Case Report. *J Korean Med Sci* 2009, **24**(Suppl):S215-8.
7. Woolfrey BF, Moody JA: Human Infections associated with *Bordetella bronchiseptica*. *Clin Microbiol Rev* 4:243-255.
8. Guthrie JL, Robertson AV, Tang P, Jamieson F, Drews SJ: Novel duplex real-time PCR assay detects *Bordetella holmesii* in specimens from patients with Pertussis-like symptoms in Ontario, Canada. *J Clin Microbiol* 2010, **48**(4):1435-7.
9. Knorr L, Fox JD, Tilley PA, Ahmed-Bentley J: Evaluation of real-time PCR for diagnosis of *Bordetella pertussis* infection. *BMC Infect Dis* 2006, **23**(6):62.
10. Poddar SK: Detection and discrimination of *B pertussis* and *B holmesii* by real-time PCR targeting IS481 using a beacon probe and probe-target melting analysis. *Mol Cell Probes* 2003, **17**(2-3):91-8.
11. Probert WS, Ely J, Schrader K, Atwell J, Nossoff A, Kwan S: Identification and Evaluation of New Target Sequences for Specific Detection of *Bordetella pertussis* by Real-Time PCR. *J Clin Microbiol* 2008, **46**(10):103228-3231.
12. Reischl U, Lehn N, Sanden GN, Loeffelholz MJ: Real-time PCR assay targeting IS481 of *Bordetella pertussis* and molecular basis for detecting *Bordetella holmesii*. *J Clin Microbiol* 2001, **39**(5):1963-6.
13. Tatti KM, Wu KH, Tondella ML, Cassidy PK, Cortese MM, Wilkins PP, Sanden GN: Development and evaluation of dual-target real-time polymerase chain reaction assays to detect *Bordetella* spp. *Diagn Microbiol Infect Dis* 2008, **61**(3):264-72.
14. Van der Zee A, Mooi FR, van Embden J, Musser JM: Molecular Evolution and Host Adaptation of *Bordetella* spp.:Phylogenetic Analysis Using Multilocus Enzyme Electrophoresis and Typing with Three Insertion Sequences. *J Bacteriol* 1997, **179**(21):6609-6617.
15. Vilemeyer O, Crouch JY, Edberg SC, Howe JG: Identification of *Bordetella pertussis* in a Critically Ill Human Immunodeficiency Virus-Infected Patient by Direct Genotypical Analysis of Gram-Stained Material and Discrimination from *B. holmesii* by Using a Unique *recA* Gene Restriction Enzyme Site. *J Clin Microbiol* 2004, **42**(2):847-849.
16. Muyldermans G, Soetens O, Antoine M, Bruisten S, Vincart B, Doucet-Populaire F, Fry NK, Olcén P, Scheffcl JM, Senterre JM, van der Zee A, Riffelmann M, Piérard D, Lauwers S: External quality assessment for molecular detection of *Bordetella pertussis* in European laboratories. *J Clin Microbiol* 2005, **43**(1):30-5.
17. Niesters HG: Quantitation of viral load using real-time amplification techniques. *Methods* 25:419-429.
18. Antila M, He Q, de Jong C, Aarts I, Verbakel H, Bruisten S, Keller S, Haanperä M, Mäkinen J, Eerola E, Viljanen MK, Mertsola J, van der Zee A: *Bordetella holmesii* DNA is not detected in nasopharyngeal swabs from Finnish and Dutch patients with suspected pertussis. *J Med Microbiol* 2006, **55**:1043-51.

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